INFLUENCE OF THICKNESS ON THE ELECTROMECHANICAL PROPERTIES OF 2-2 CEMENT BASED COMPOSITE

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Abstract

A 2-2 type cement based piezoelectric composite was fabricated by dice-and-fill technique. The effects of the composite thickness on and electromechanical properties of the composite were analyzed. The results show that both the thickness electromechanical coupling coefficient $K_t$ and the mechanical quality factor $Q_m$ exhibit the trend of decrease with the increasing of the thickness. With the increase of the thickness, the acoustic impedance of the composite changes little, which fluctuates between 16 and 17 M rayl.

1. INTRODUCTION

In the past two decades, piezoelectric composites have been widely used in a number of electromechanical transducers such as hydrophones, vibration sensors, and pressure and stress sensors because they can offer both fabrication and performance advantages over monolithic ceramic and piezoelectric polymer transducers [1-3]. Recently, along with the development of smart materials in the health monitoring and active-vibration control of structures in civil engineering fields, cement based piezoelectric composite gains more attentions because of its superior piezoelectric properties and good compatibility with concrete.

Li et al [4] first reported 0-3 cement based piezoelectric composites using Portland cement as matrix and PZT ceramic as piezoelectric component by mixing and spreading method. Subsequently, 1-3 and 2-2 connectivity cement based piezoelectric smart composites were also developed gradually [5-8]. However, the research of electromechanical properties for 2-2 cement based composite is still little. In this work, a 2-2 PMN ceramic/sulphoaluminate cement based piezoelectric composite was fabricated by dice-and-fill technique, and the influences of the composite thickness on the electromechanical properties of the composite were studied.

2. EXPERIMENTAL PROCEDURES

A 2-2 cement based piezoelectric composite was fabricated by a dice-and-fill technique using sulphoaluminate cement and PMN ceramic as raw materials. The piezoelectric ceramic
was cut using WSQ50 diamond cutter (Maike Material Processing Corporation of Shenyang, China) in the parallel direction with polarization axis of the piezoelectric ceramic. After cut, the ceramic plates were washed. Then the samples were put into the mould for casting cement (water-cement ratio (by weight)=0.35) with continuously vibrating. After casting, the fabricated composites were moist-cured (temperature 20±1°C, relative humidity 90%) for 7 days. Before spreading the electrode, the upper and lower surfaces of the composite were polished until the ceramic plates of the two surfaces appear completely. After polishing, a silver paint was applied on the surfaces of the composites for measurement. The thickness of each fabricated composite is 10.0 mm, 9.0 mm, 6.6 mm, 3.9 mm, 2.6 mm, respectively. The spacing of the ceramic plates is 1 mm, and the width for every ceramic plate is also 1 mm. The PMN ceramic volume fraction for each composite is 53.9%. Fig.1 is the schematic illustration of 2-2 sulphoaluminate cement based piezoelectric composite.

![Schematic illustration of 2-2 cement based piezoelectric composite](image)

**Figure 1: Schematic illustration of 2-2 cement based piezoelectric composite**

Electromechanical coupling coefficient \( K_t \) and mechanical quality factor \( Q_m \) were calculated by the following equations [9],

\[
K_t^2 = \frac{\pi}{2} \cdot \frac{f_s}{f_p} \cdot \tan\left(\frac{\pi}{2} \cdot \frac{f_p - f_s}{f_p}\right)
\]

\[
Q_m = \frac{1}{2\pi f_s RC \cdot \left(\frac{f_p^2 - f_s^2}{f_p^2}\right)}
\]

Where, \( f_s \) and \( f_p \) are series and parallel resonance frequency, respectively, which can be approximate replaced by frequency \( f_m \) and \( f_n \), that is, \( f_s \approx f_m \), \( f_p \approx f_n \). \( R \) is the minimum impedance value.

In order to calculate \( K_t \) and \( Q_m \), an Agilent 4294A Impedance Phase Analyzer was used to measure capacitance(\( C \)), resonance frequency (\( f_m \)), anti-resonance frequency (\( f_n \)) and impedance (\( R \)) of 2-2 cement based piezoelectric composite, respectively.

3. RESULTS AND DISCUSSION

Fig.2 is the impedance spectra of the composite with different thickness. It can be seen that with the decrease of the thickness, there appears fewer unorderly peaks around the thickness.
Fig. 2. Variation of impedance and phase of the composite with frequency (the right part is the local magnified around the thickness mode)
resonance peak of the composite. The reason may be that the less the thickness, the larger the thickness resonance frequency than the planar resonance frequency, which avoids the coupling of the two kinds different resonances, accordingly, the thickness mode is hardly influenced by the planar mode, which is significant to the fabrication of the ultrasonic sensors.

Table 1 shows the thickness mode electromechanical coupling properties of the composite. It is seen that with the increase of the composite thickness, both the series ($f_s$) and parallel ($f_p$) resonance frequency decrease gradually, and the frequency band ($\Delta f$) of the composite also gradually decreases. Both the thickness electromechanical coupling coefficient $K_t$ and the mechanical quality factor $Q_m$ show the trend of decrease with the increase of thickness. When the composite thickness decreases to 2.6mm, the thickness electromechanical coupling coefficient $K_t$ can reach to 52.26%, which means the superior electromechanical conversion capability of the composite. The less the composite thickness, the larger the mechanics quality factor $Q_m$, which is also advantage to reduce the loss of mechanical energy.

Table 1 The electromechanical properties and acoustic impedance of the composite

<table>
<thead>
<tr>
<th>Thickness/mm</th>
<th>C/pF</th>
<th>$f_s$/kHz</th>
<th>$f_p$/kHz</th>
<th>$\Delta f$/kHz</th>
<th>$R$/Ω</th>
<th>$K_t$/%</th>
<th>$Q_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>1350</td>
<td>656.29</td>
<td>750.03</td>
<td>93.74</td>
<td>54.54</td>
<td>52.26</td>
<td>14.12</td>
</tr>
<tr>
<td>3.9</td>
<td>968</td>
<td>431.29</td>
<td>481.29</td>
<td>50.00</td>
<td>136.75</td>
<td>48.12</td>
<td>14.14</td>
</tr>
<tr>
<td>6.6</td>
<td>631</td>
<td>255.03</td>
<td>282.53</td>
<td>27.50</td>
<td>420.45</td>
<td>46.72</td>
<td>12.08</td>
</tr>
<tr>
<td>9.0</td>
<td>602</td>
<td>175.04</td>
<td>193.79</td>
<td>18.75</td>
<td>720.46</td>
<td>46.59</td>
<td>11.40</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

A 2-2 type cement based piezoelectric composite was fabricated by dice-and-fill technique. Both the thickness electromechaneical coupling coefficient $K_t$ and mechanical quality factor $Q_m$ exhibit the trend of decrease with increasing the composite thickness. With the increase of the thickness, the acoustic impedance of the composite changes little, which fluctuates between 16 and 17 M rayl.

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REFERENCES


